

Fatal Gas Explosion of a Residential Building: Three Levels of "Lessons Learned"

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Introduction

The hazardous potential of natural gas concerns production as well as transport and the environment of end users.

The following presentation is the report of a case study of a very severe gas-explosion in the end-user's environment and deals with an explosion in a brick-stone residential building in Wilhelmsburg, a community in Lower Austria, on December 2, 1999, which resulted in total collapse of the building. The incident caused ten fatalities (nine within the building, one passing by). Only one inhabitant, a 17-year old girl, survived in a small hollow sphere of the rubble of ruins.

The investigation was carried out by a team of experts with expertise in explosion effects, ballistics, metallurgy, polymer chemistry, building engineering, ground mechanics and fluid dynamics, forensic pathology, gas-analysis, and management of gas-supply infrastructure.

The investigation included also 1:1-scale trials of gas-explosions within structures as a tool for interpretation and verification of the evidences of the explosion.

The very comprehensive investigation and analysis was the key to successful understanding of what had happened and to draw conclusions for management of emergency situations concerning accidental releases of natural gas in the end user's environment.

Chronology of the Events

Approximately 15:00: *During grounding-work for a lightning-arrester a gas-pipeline is severely damaged. The location is near the staircase of the residential building CONRAD-LESTER HOF 4/1.*

- The damage caused a leak of approx. 7500mm^2 in the pipeline of the dimension DN 100.
- The rate of leakage was calculated to be at least $350\text{ m}^3/\text{h}$ and $700\text{ m}^3/\text{h}$ at maximum.

15:35: *The workman who caused this damage calls the responsible gas-supplier.*

15:40: *The person in duty of the responsible emergency staff of the gas-supply-company is leaving his office.*

15:55: *The person of the emergency staff arrives. After a first sight he calls for the assistance of a building-company with an excavator.*

- Concentration measurements were carried out in the staircase of the nearby building, CONRAD-LESTER HOF 4/1, at that time, showing concentrations between 5 and 15 percent vol, locally even going up to 40 percent vol.
- The gas was entering mainly through holes and cracks around cables of electricity, which were passing through the wall in that part of the building.

The electricity is shut down.

16:10: *The person of the emergency staff calls for further assistance. In the meantime he tries to minimize the entering of gas by sealing the cracks and holes in the wall with a special tape.*

16:15: *He initiates evacuation of the building. This is readily assisted by the police, as the police station is accommodated in a nearby building.*

Until 17:15: *With the help of the excavator the damaged gas pipeline is excavated. The final layer of soil is removed manually. The pipeline is repaired with a tape without shutting down the gas supply.*

- The measurements in the staircase and in some parts of the cellar, which were conducted shortly after the repair was finished, showed concentrations of natural gas up to 0,3 percent, as was told afterwards.

17:50: *Electricity is turned on again.*

18:00: *Inhabitants are allowed to return to their flats.*

18:30: *Explosion causing complete collapse of CONRAD-LESTER HOF 4/1.*

The ignition-source was probably a freezer, which was located in one of the compartments of the remote cellar-room. After the period without electricity, which lasted for about one and a half hours, the freezer started after the turn on. After a running period of approximately 40 minutes the temperature-limit was reached again. The freezer switched off and a spark was created by breaking off the circuit. As the freezer was surrounded by an ignitable atmosphere, the explosion was initiated.

This hypothesis could not be verified, but it remained the most probable one.

Technical Analysis:

Resistance of the Structure

- The resistance of the walls of the cellar with respect to overpressure was estimated to be approximately 0,2 to 0,3 bar.

- This value is also valid for the walls of the upper floors.
- The tolerable pressure-load to the ceilings was estimated to be 0,1 to 0,12 bar for forces from above and 2/3 of that, if forces are attacking from the bottom, which was the case with the explosion.

The walls of the upper floors were made of brick-stone the walls of the cellar were made of unreinforced concrete.

This type of construction leads to very small fractures in the case of a collapse, with very little chances for building up hollow spaces within the heap of rubble.

Stream of Gas into the Cellar

The location of the damage to the pipeline was only 50 cm away from an inlet of cables of electricity through the wall in the area of the staircase.

The mobility of gas in the ground was such that only up to a distance of approximately 2 m from the leak the driving pressure would have been high enough to enable the entering of significant amounts of gas through holes and cracks in the walls of the cellar of that building.

Unfortunately the largest porous part of the cellar walls was in the vicinity of the leak, only 50 cm away from the leak. So at least one third of the total escaping amount of gas was directly led into the cellar.

- This amount corresponds to approximately 1500 to 3000 m³ of stoichiometric gas-air mixture.
- This is two to four times the total inner volume of the building! So it was not only very bad luck to hit the pipeline but it was even worse that this happened very close to a rather porous structure of the wall. To make bad luck complete, this inlet was in the area of the staircase, which gave further support to unhindered spread into the building.

Location and Strength of the Explosion

Judging from the remains of the walls (orientation), the characteristics of the flight of debris (parts of window frames up to 5 kg at 30–35 m distance) and the injuries of the victims (broken legs and penetrations of debris), *the explosion had started somewhere in the remote part of the cellar and was growing up towards the second block of the building* which did not collapse.

The explosion caused very strong upward acceleration of the ceiling of the basement and also appreciable acceleration of the ceiling of the ground floor, as indicated by the leg-injuries of the inhabitants of the ground floor and to lesser extend to the inhabitants of the first floor.

The remote cellar room consisted of compartments divided only by wooden lattice and accessible by a long corridor.

The compartments of the remote cellar-room were used for storage and most of them were full with stored items. *So from the point of view of a gas explosion the cellar is a confined room with elongated geometry and a high blockage ratio—and provides all requirements for acceleration of a gas explosion by turbulent propagation to the utmost violence.*

The ratio of ventilation area (cross section of windows and door) of the remote cellar room to total volume would lead to an upper pressure limit of 1,5–2 bar, if the structure would resist.

As the resistance of the structure is limited by approximately 0,2 bar, the maximum pressure of the explosion was significantly lower.

Some window-frames were accelerated by the flow of the escaping gases—judging from their trajectory, the initial velocity was in the range of 50 m/s and the overpressure not higher than 0,5 bar.

Analysis of the Wounding Characteristics of the Victims

All victims were discovered on locations of vertical projection of their flats. So it was concluded, that all of them have been at their home (not visiting neighbors or using the staircase) at the moment of explosion.

Fractures on legs caused by strong acceleration from below, showed strong indications with inhabitants of ground-floor, lesser extent with inhabitants of first floor. Also penetrations from upgoing material were found. No such indication was detected with victims of the upper two stories.

Natural gas was detected in the lungs of all victims.

- The pattern of injuries correlated with the start of the explosion in the cellar.

Amount of Gas Involved

Following a rule of thumb, to develop an explosion starting in the remote area of a ventilated structure with maximum pressure of approximately 1 bar, only 30 percent of the room have to be filled with a stoichiometric mixture.

The remote cellar room had a total volume of 255 m³, if all of the compartments had been completely empty.

- To fill one third of this room with a stoichiometric mixture, only 8,5 m³ of gas are necessary.
- This is only less than 2 percent of the total amount of natural gas which had entered the building! Measurement of gas concentration

The emergency staff was equipped with two devices for gas detection. Both were functioning well. One was a device for measurement of gas concentrations up to levels of 100 percent natural gas. The second one was a sensitive sniffer, mainly designed for leak detection of buried pipelines, which gave an alarm with concentrations above 0,2 percent vol.

After arrival, the measurements in the staircase in the cellar showed concentration of up to 40 percent vol, before the holes and cracks in the wall were closed and windows were opened for ventilation.

- Later statements of the involved workmen were not consistent. But it was a fact that they had not carried out control measurements in all rooms of the cellar.

- Obviously they had not been aware of the strange pattern of spread of gas in the presence of streams of convection.

Trials in Bunkers

Trials were carried out in bunkers to reveal some aspects of interrelation of the function of vents and pressure build-up.

Preliminary experiments for testing the measurement- equipment were carried out in concrete structures covered by plates of steel of a weight of 1100 kg and 1800 kg.

The steel-plate is moved up by the pressure of the gas explosion and the hot burning gases are escaping with high velocity. The pressure is limited and maintained by the weight of the covering plate and was 0,32 bar with the 1100 kg plate and 0,58 bar with the heavier 1800 kg plate.

Two bunkers were used for the experiments: Bunker No. 1 and Bunker No. 2.

Bunker No. 1:

Bunker No. 1 was built up of 25 cm diameter reinforced concrete-walls, and also a ceiling of reinforced concrete 25 cm thickness. The reinforcing iron was also connecting the ceiling to the walls. The structure was designed to withstand pressures up to 3 bar. In the ceiling there was a square-shaped opening with 70 cm in diameter (0,49m² ventilation area). For the experiment this hole was closed by a fibre board and sealed with silicon, just for convenient filling with gas.

Bunker No. 2:

The second bunker used was built up by 25 cm concrete blocks.

The ceiling was also made of 25 cm reinforced concrete and originally also connected to the walls. It has been used for explosion experiments before and the ceiling was at least partly lifted up during these experiments. *So technically the situation was a free resting ceiling, comparable to common design of residential buildings as it was the case of the collapsed building at Wilhelmsburg.* The opening in the ceiling was blocked by a wooden plate of 4 cm thickness, fixed from inside.

Results:

Bunker No. 1 showed a rather slow increase of pressure in the beginning, taking 40 ms up to 0,6 bar, followed by stronger steeper increase within 15 ms up to 1,8 and 2,4 bar in a repeat of the test.

The acceleration of the increase starts some time after the opening of the vent, as the escaping gases cause increased turbulence within the structure, thus accelerating the burning reaction.

The pressure is rising up to a level which is in accordance with rules of thumb for pressure build-up in vented structures.

Bunker No. 2 showed a larger increase of pressure in the beginning, as the opening remains closed for a longer period as with experiment 1, reaching 0,6 bar after 25 ms. As the whole ceiling is lifting up and bursting at that moment, there is no more pressure-increase during the remaining run of the explosion.

This behaviour reflects what had happened in Wilhelmsburg.

Conclusions

Three levels of lessons learned: first lesson:

First lesson: Vulnerability of the end-users environment

The end-user environment of the natural gas supply chain is a vulnerable target.

The release of comparatively small amounts of gas (less than 10 Nm³), as it might happen accidentally or by sabotage, can lead to fatal incidents with large residential buildings.

Manipulation on gas supply facilities in the vicinity of a building or inside the building (flowcounters, pipeline, consuming devices such as an oven or continuous flow heater) can create dangerous concentrations of natural gas very easily and quickly.

The gas might enter a building also through “sealed walls”.

Always keep aware of possible oddities or shortcomings or imperfections of constructions, one would not expect based on plans or the level of state of art or the anticipated level of carefulness.

Second lesson: Successful cooperation of a network of expertise

The successful solving of the incident was due to co-working of many experts, representing a variety of expertise, to make full advantage of all the evidence one was able to collect after that incident.

Full-scale experiments reveal a very good insight to interrelation of development of reaction and pressure of a gas explosion and structural response. The comparative study of gas explosions in bunkers, using high-speed cameras, revealed interesting and instructive patterns of the development of the explosion and are a valuable tool in evaluating rules of thumb.

The reconstruction of the incident could be resolved only by multidisciplinary teamwork:

Construction engineers to characterize the behavior of the building in response to overpressure.

Experts on gas explosions to evaluate the effects of pressure, heat and flight of debris and sources of ignition.

Experts on Ballistics to draw conclusion from fly of debris.

Experts on Pathology to draw conclusions concerning the center and spatial development of the explosion.

Experts on Metallurgy to rule out manipulation on flow-counters and other devices (suspicion of sabotage).

Experts on gas-supply management to evaluate the emergency management of the gas supplier and to give an estimate on the leakage rate.

Experts on ground mechanics and fluid dynamics to give an estimate on the flow of gas in the ground and through the wall of the building.

Experts on gas analysis to evaluate the detectability of dangerous gas concentrations and the dissipation of gas throughout a building by mechanisms of diffusion and convection.

Third lesson: Education of emergency response staff

The careful control of the complete area concerning remaining gas-concentrations is a key strategy for successful emergency repair. The ability to carry out this control has the requirement of deep understanding the odd possibilities of dissipation of those gas releases.

The dissipation of natural gas can follow very strange ways one would not think of without senior experience.

Education of emergency staff with respect to these requirements is of great importance.

The accident described in this presentation was a chain of unfortunate incidents.

But with the proper awareness of the behavior characteristics of the spreading of accidental releases of natural gas, the remaining concentrations would have been detected.

The person in charge even had been on an internal education the day before, concerning repair of a pipeline! Strategies of reducing personal costs might also affect the emergency staff.

In this case, the emergency response staff was simply understaffed: *for most of the time one single person did the organization, the repair of the leak and the monitoring of hazardous gas concentrations*. There was no superior control or coordination, which would be mandatory with events of a level of severity as it was the case.

The persons of the emergency response staff were simply overcharged: So finally they were sentenced and have to live on with the burden of 10 fatalities, though they had been doing a lot of right things at the right time and had been making more right decisions than one single person should be responsible for in such a situation.

They simply failed, finally, because of the oddity of dissipation of natural gas, they obviously have not been aware of and have not been educated about well enough.

There is always a tendency to reduce staff. And it might be attractive to cut emergency response staff, at first glance because people might only be waiting 90 percent of their time on duty.

The question is: shall we afford personal who is needed maybe one time in two years to handle emergency situations of the size of Wilhelmsburg? Or shall we reduce staff and reduce educational activities and tolerate incidents like that from time to time?

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